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HEAT LEAK MEASUREMENTS ON ENERGY DOUBLER DIPOLE SUPPORT MODEL G10-1

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Abstract

A simple yet powerful technique for measuring suspension system heat losses for cryogenic magnets has been developed. The techniques used are more similar to those used in thermal conductivity measurements in contrast to the more usual calorimetry techniques.

HEAT LEAK MEASUREMENTS ON ENERGY DOUBLER DIPOLE SUPPORT MODEL G10-1

The structural support member for the Energy Doubler dipole here referred to as Model G10-1 is made out of epoxy fiberglass NEMA-G10 with a shape based on the Magnetic Corporation of America Drawing: MCA #D-2282-A. Members of this type are used in the 20 foot prototype Magnet #3. An actual drawing of the support structure is included as Appendix A.

The values of 11.9K/watt (±8%) and 153K/watt (±20%) were obtained for the thermal resistance of this support between the shield and the liquid helium and between the room temperature tube and shield respectively (for shield temperatures below 40K, when the thermal conducitivity of NEMA-G10 is practically temperature independent). Our measurements show that this support will leak $\frac{20-4.2}{11.9} = 1.33$ watts into the 2-phase-helium at 4.2K and deposit $\frac{300-20}{153} - 1.33 = .5$ watts into the shield refrigerator. The original MCA design[1] estimated .11 watts and .63 watts respectively. The main problem in the design of this support is the location of the 20K shield which short circuits lengths of G10 and is separated from the 4.2K contact areas only by short and thick G10 volumes. Another problem, circumvented in these measurements by elaborate superinsulation, is the radiation characteristic of the slots in the G10. Radiation heat leak can be considerable, as much as 3 watts per support member is estimated to have radiated into the 20K shield of Magnet #3. Values up to 2.6 watts in our set-up were inferred from the measurements. These values are in agreement with calculations based on the Stephan Boltzmann law, for emissivities of the order of 0.5 .

A method based on comparing changes of the heat flow in the support with the changes of the heat flowing through copper "reference-heat-resistors" is used to make these measurements in contrast to the more usual boil off measurements since it yields more information from better controlled conditions. In spite of its conceptual simplicity and elegance this method has not been used before (as far as the authors are aware) perhaps because it involves careful instrumentation of the set-up. The techniques involved, however, are typical of thermal conductivity measurements.

A total of 6 runs (carried on from Sept. 7, 1974 to Sept. 27, 1974) were used to debug the set-up, check the method and measure the thermal conductance of the support in two different ways. Agreement of the results, self consistency on intermediate measurements and knowledge of the radiation heat leak involved were obtained.

The support is instrumented with thermometer T_R and heater Q_1 in its room temperature tube and with thermometer T_S and heater Q_2 in its shield. It is installed around a solid cylindrical copper block with thermometer T_H, that simulates the magnet and forms the cold bottom of an unshielded helium dewar. The support is therefore in the vacuum space of this dewar with its room temperature tube parallel to and facing the external dewar wall, as shown in Figure 1. A carefully machined and installed copper strap, R_3, cools the shield by connecting it to the copper block.

Considering only heat flow by conduction, this system may be represented by the thermal circuit indicated in Figure 2. Analogy with electrical circuits is obtained by equating electrical potential with temperature and electrical current with heat flow. R_1 and R_2 are the thermal resistance of the two sections of the support. They are the unknowns of our problem. The other elements in this circuit are:

T_R = temperature of the room temperature tube

Q_1 = heat electrically delivered to the room temperature tube

T_S = temperature of the shield (around 20K)

Q_2 = heat electrically delivered to the shield

T_H = temperature of the copper block (close to 4.2K)

R_3 = thermal resistance of the copper strap (reference-heat-resistor).

Two independent ways are used to measure R_2. In both cases Q_1 is adjusted to bring T_R to room temperature (the time constant is large and the value of Q_1 is not very sensitive on T_S). In the first way T_S is then measured as a function of Q_2. The slope $\frac{dT_S}{dQ_2}$ is given by

$$\frac{dT_S}{dQ_2} = \frac{R_2 R_3}{R_2+R_3} \quad . \tag{1}$$

We could get R_2 if R_3 were known. The use of slopes permits us to obtain our measurement in spite of the radiation heat leak into the shield. In order not to depend on the knowledge of the value of R_3 in this first way we repeat the measurements a second time but using now, instead of one strap, two identically machined straps (out of the same copper sheet) in parallel. So now we have

$$\frac{dT_S'}{dQ_2'} = \frac{1}{2} \frac{R_2 R_3}{R_2 + \frac{1}{2} R_3} \quad . \qquad (2)$$

From the two measured slopes $\frac{dT_S}{dQ_2}$ and $\frac{dT_S'}{dQ_2'}$ and equations (1) and (2) we get the values of both R_2 and R_3. Figure 3 shows the data plotted with other relevant information. The values of the slopes and intersections were obtained by least square fitting the data points to straight lines.

The other independent way requires the simultaneous use of two identical straps R_3. The circuit is shown in Figure 4. Actually double straps $\frac{1}{2}R_3$ were used. The additional heater Q_3 and thermometer $T_{S'}$ allow direct measurement of $\frac{1}{2}R_3$, from the slope of the T_S' vs. Q_3 plot:

$$\frac{dT_S'}{dQ_3} = \frac{1}{2} R_3$$

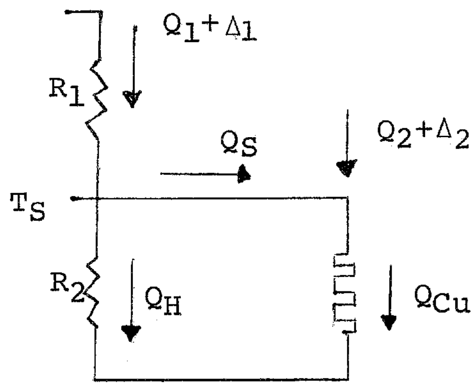
Figure 5 shows the data, which deviates from a straight line because the thermal conductivity of the copper is temperature dependent. By least square fitting to a straight line the points in the temperature region of T_S we get the appropriate value of $\frac{1}{2}R_3$. Another plot is obtained for pairs of values of Q_2 and Q_3 that render $T_S = T_S'$. A thermocouple connecting T_S to T_S' was used to verify physically this equality. Under this condition the value of R_2 is determined from the slope $\frac{dQ_2}{dQ_3}$ and the measured $\frac{1}{2}R_3$ through the equation

$$R_2 = \frac{\frac{1}{2}R_3}{\frac{dQ_2}{dQ_3} - 1}$$

Figure 6 shows the data obtained in two different runs. The value of the slope is again obtained by least square fitting to a straight line. It is relevant to point out that this second way requires just one cooldown.

A careful observation of Figures 3 and 5 reveals the existence of heat flowing through the system besides Q_1, Q_2 and Q_3. This extra heat must be coming in by radiation. In order to get a quantitative knowledge of this heat leak we label Δ_1, Δ_2 and Δ_3 the extra heat shining into or out from the room temperature tube, shield and reference block T_S' respectively. The values for these heat leaks are very dependent on the shielding provided by a copper disc (disc shield) that intercepted the infrared light coming from the bottom of the dewar. Lack of superinsulation on it during the 4th run explains why the shield and even the copper block T_H were hotter than in the 3rd run.

The measurement of R_1 to the same degree of accuracy as R_2 would involve much greater effort since we have superinsulation in parallel with R_1 and much longer time constants are involved. Assuming that Δ_1 was zero in the 6th run (in which T_R was best matched to the temperature of the outside dewar wall), we get the value of 153K/watt. With this value we can analyze the data of previous runs, and assign values for Δ_1, Δ_2 and Δ_3 as well as the heat flowing through each element when $Q_2 = 0$.



Run #	Q_1	Δ_1	Δ_2	Q_H	Q_{Cu}	Q_S (watts)
3	3.10	-1.27	1.28	2.16	.95	-.33
4	2.19	- .43	2.62	2.33	2.05	-.57
5	2.18	- .37	2.16	2.04	1.93	-.23
6	1.76	0	2.19	2.03	1.92	-.27

The above values of Δ_2 indicate that radiation heat leak is a major contribution and careful superinsulation of the Doubler will be necessary.

The instrumentation was implemented with a calibrated Ge thermometer for T_S and a platinum thermometer for T_R which was calibrated by us in the range of interest. From the Au-.07% Fe vs. chromel thermocouple and the data collected we got provisional spot calibration for the other germanium thermometers (T_H and T_S) as by-products of the test. Measurements of thermometer resistance and power dissipated in the heaters were made with 4-lead techniques. Care was taken to heat-sink properly all thermometer leads and heaters. The value R_2 = 11.7K/watt is an average of the values obtained by the two independent ways used and the error reported (±8%) covers both values. A more careful study of error sources and propagation does not seem warranted. It would involve, for instance, an experimental study of the contact resistance at the attachment points of the reference-heat-resistors (indium gaskets .005" thick were used at these points). The agreement between the results of the two independent ways and the purpose of the test seem to justify this attitude. The 20% error for R_1 = 153K/watt is however only an educated guess.

We would like to acknowledge the contribution of G.Biallas on the design of cryostat components and thank D.J.Drickey for his encouragement, support and contribution to the final form of the manuscript.

References:

1. Superconducting Energy Doubler Dipole Design Study, Z.J.J.Stekly, R.J.Thome, R.A.Ackermann and J.M.Tarrh, Magnetic Corporation of America, Vol. I, page 60.

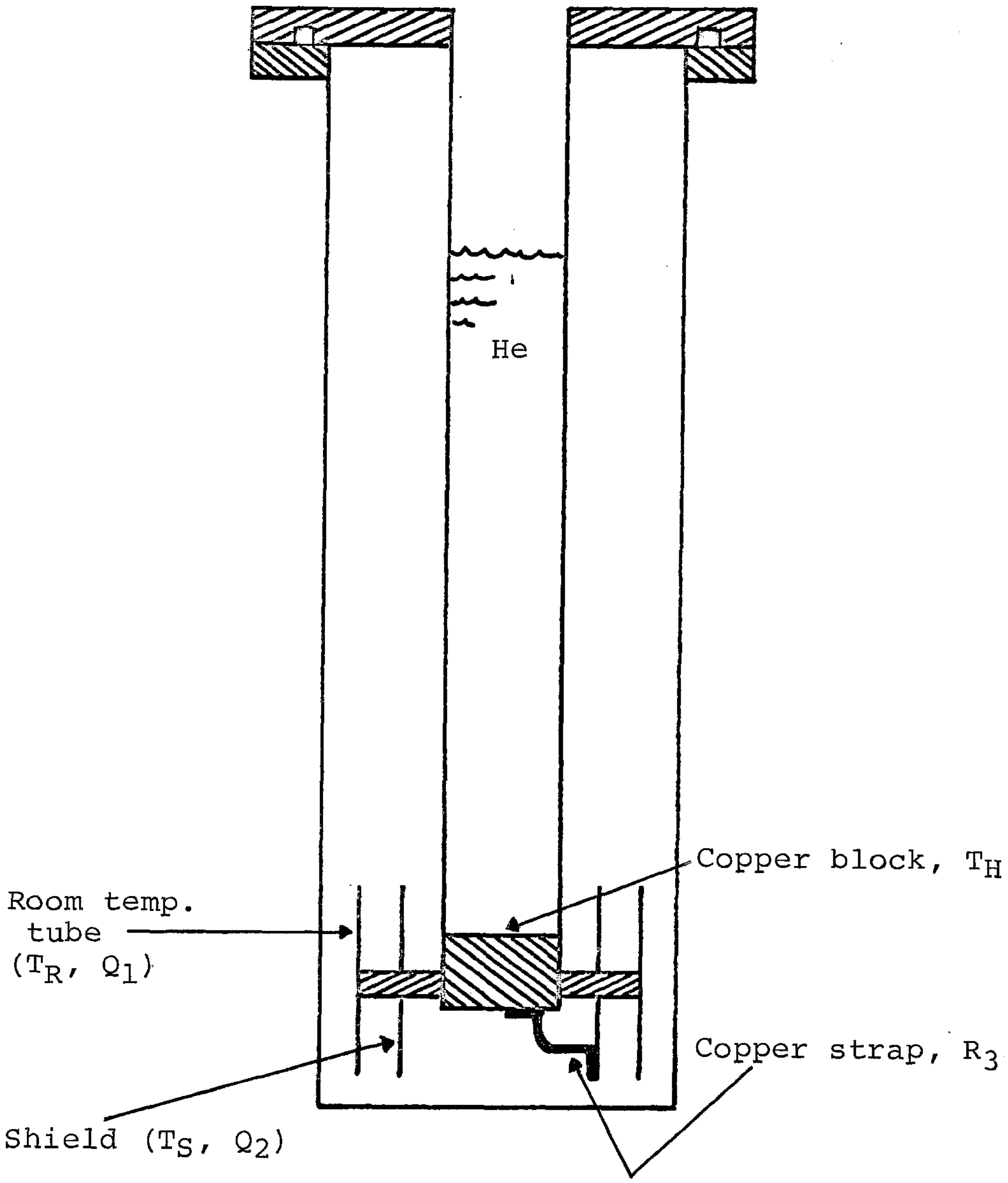


Figure 1.
Simplified drawing of the apparatus.

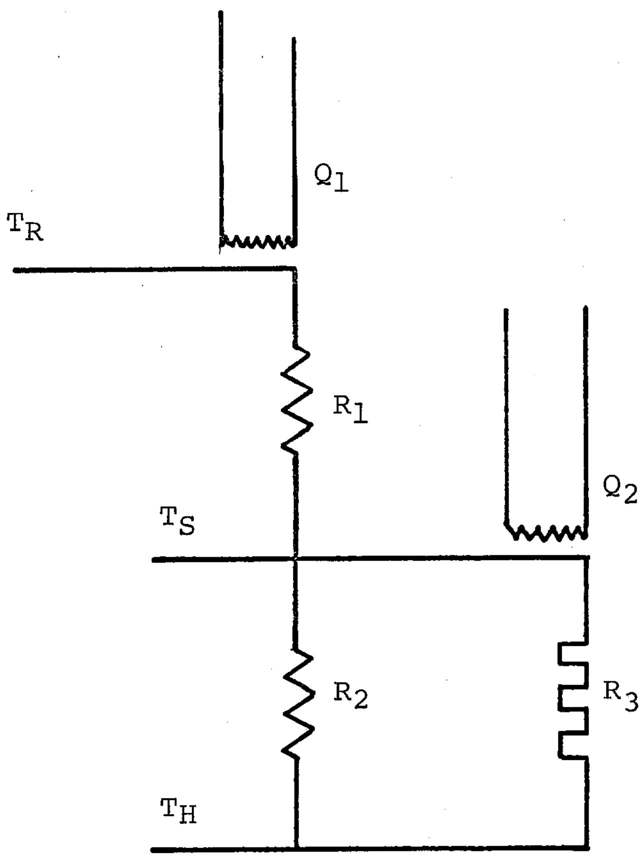


Figure 2.
Schematic of the thermal circuit.

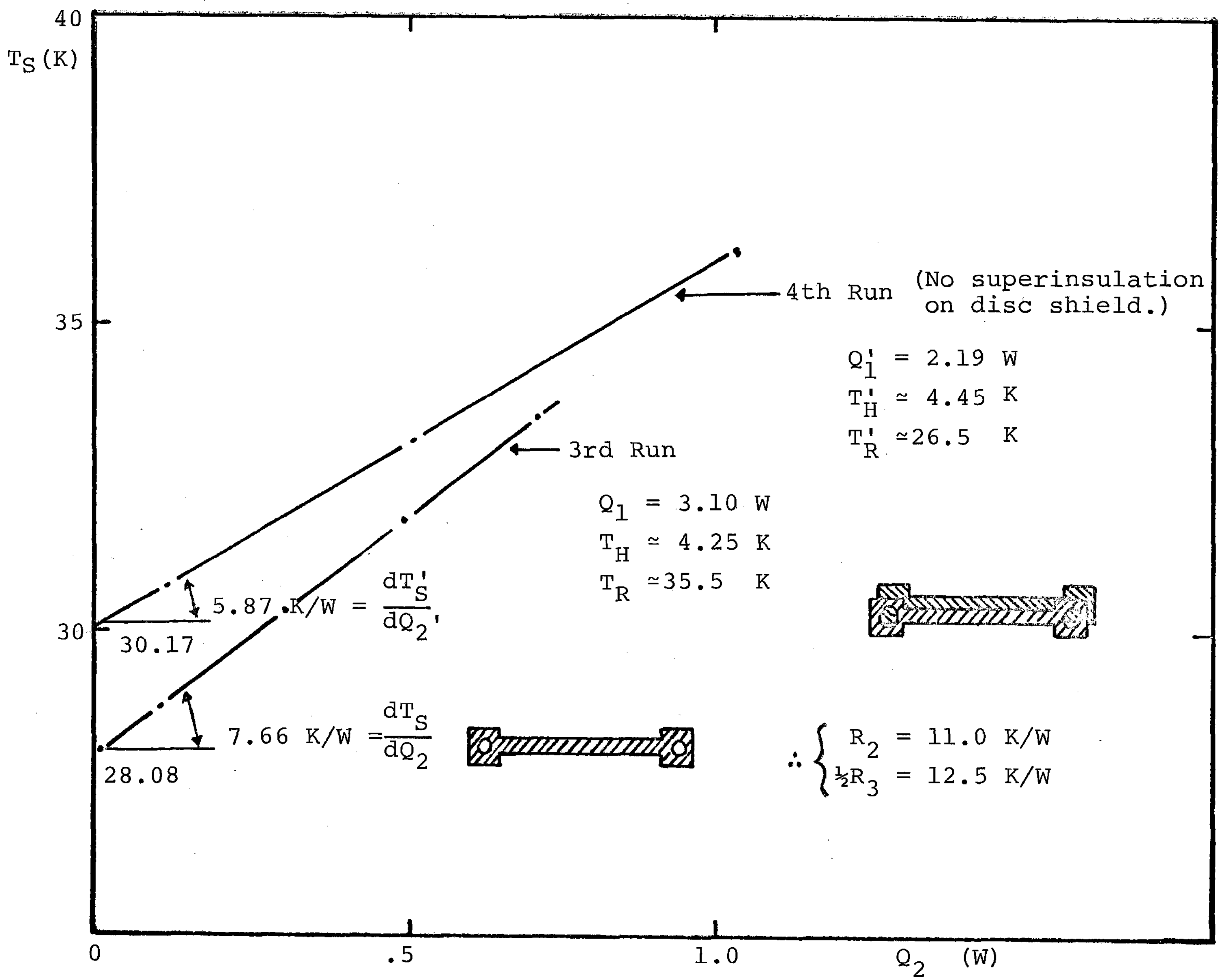


Figure 3.

Shield temperature vs. change in shield heat input.

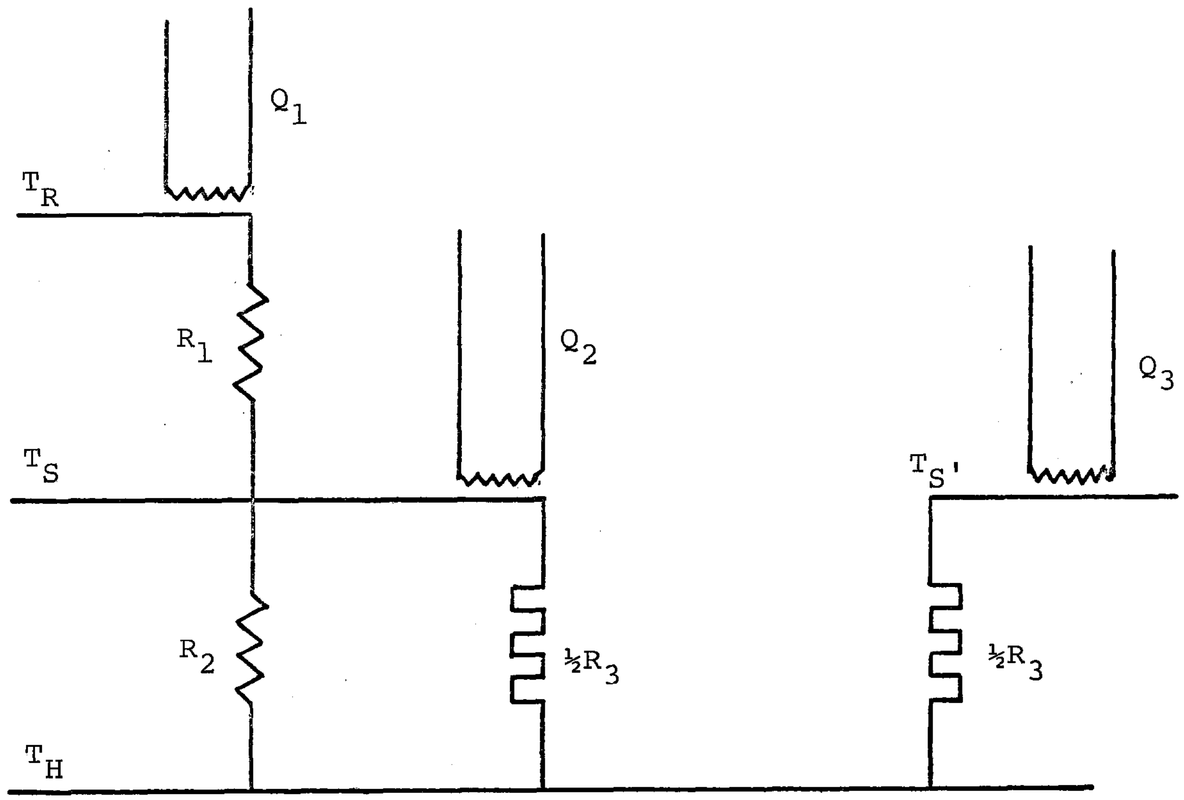


Figure 4.
Thermal circuit involved in the second way.

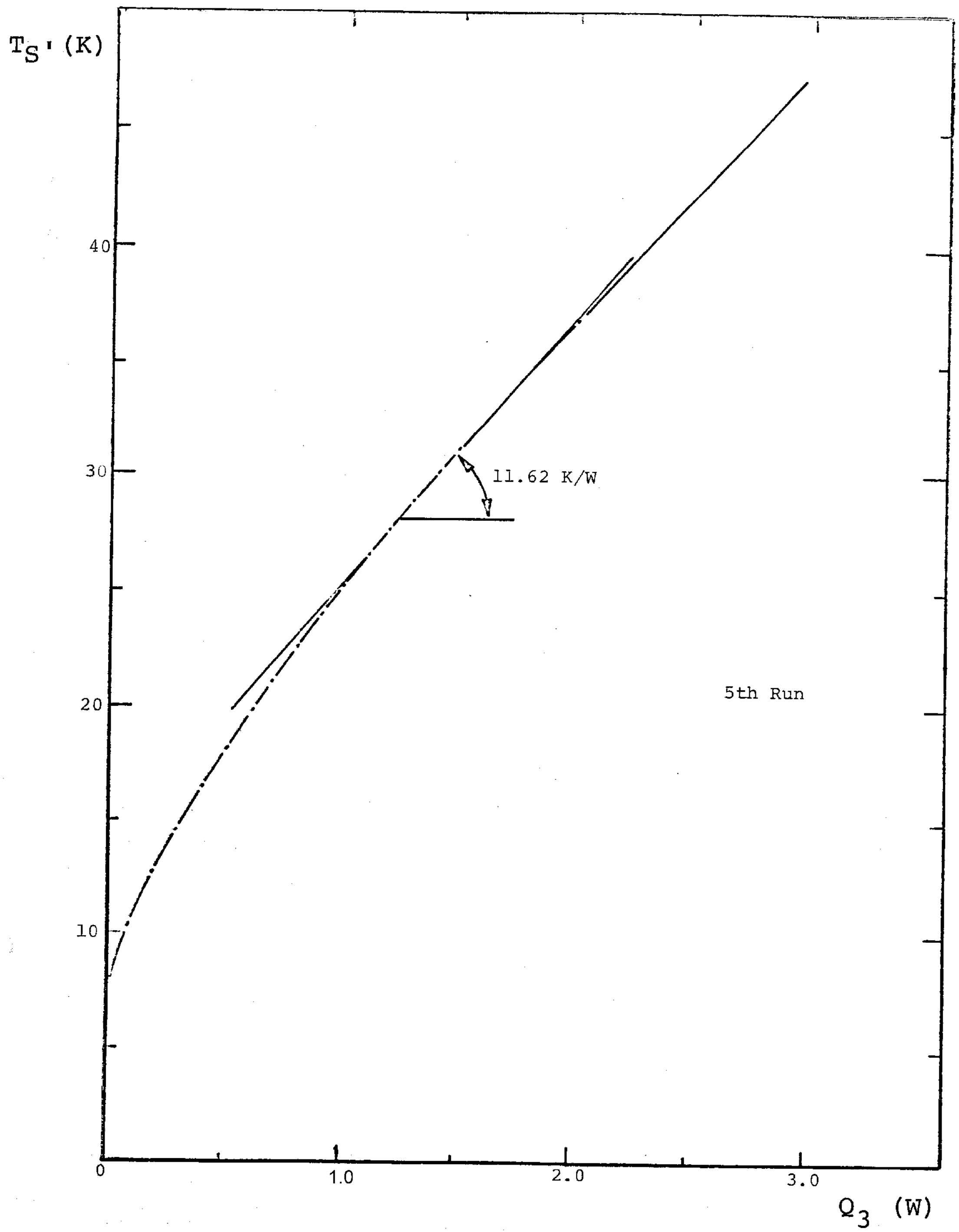


Figure 5.
$\frac{1}{2}R_3$ Thermal resistance.

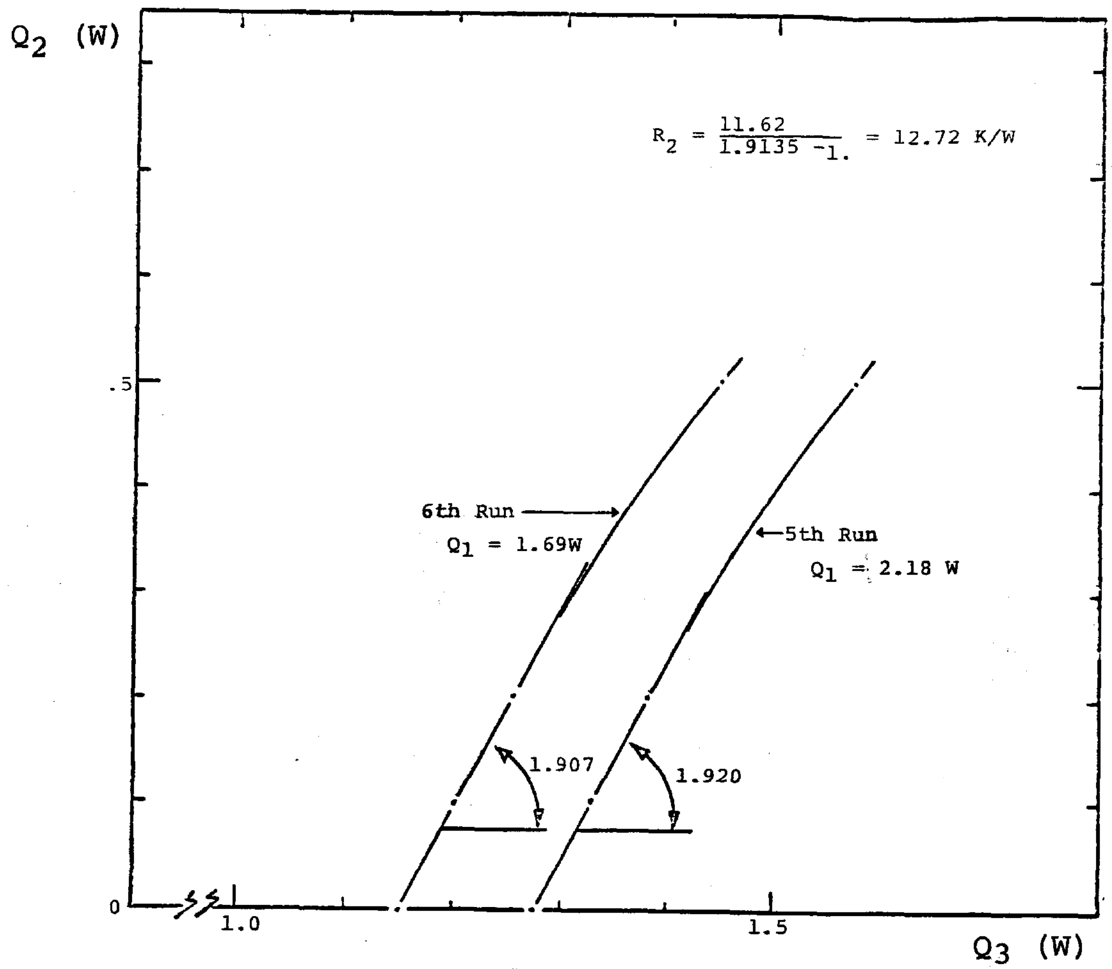


Figure 6.

Comparison between heat through R_2 and R_3.

APPENDIX A

Fermilab Drawing 0428-MC-53886